PCT/AU00/00696

28/12

REC'D 11 JUL 2000

WIPO PCT

PRIORITY DOCUMENT

SUBMITTED OR TRANSMITTED IN COMPLIANCE WITH RULE 17.1(a) OR (b)

Patent Office
Canberra

4

I, KAY WARD, TEAM LEADER EXAMINATION SUPPORT AND SALES hereby certify that annexed is a true copy of the Provisional specification in connection with Application No. PQ 1121 for a patent by UNISEARCH LIMITED filed on 22 June 1999.

COMMONWEALTH OF AUSTRALIA
AUSTRALIA
PATENT OFFICE

WITNESS my hand this
Fourth day of July 2000

K Ward

KAY WARD
TEAM LEADER EXAMINATION
SUPPORT AND SALES

ß

AUSTRALIA

Patents Act 1990

PROVISIONAL SPECIFICATION

Applicant(s):

UNISEARCH LIMITED

A.C.N. 000 263 025

Invention Title:

EPITAXIAL FILM

The invention is described in the following statement:

EPITAXIAL FILMS

Field of the Invention

The present invention relates broadly to the growth of epitaxial films. The invention will be described herein with reference to the growth of epitaxial zinc sulfide (ZnS) on silicon (Si) (111) substrates, but it will be appreciated that the invention does have broader applications relating to growth of epitaxial films of different materials on different substrates.

Background of the Invention

Films that grow with singular crystallographic orientation in all directions are referred to as epitaxial films. In other words, unlike poly-crystalline thin films, which include a large number of crystallites but with variable orientations with respect to each other, epitaxial films may be regarded as films formed from one single-crystal layer.

Epitaxial thin films have been produced using a variety of different techniques, including molecular beam epitaxy (MBE), vapour phase epitaxy (VPE) and atomic layer epitaxy (ALE). However, a common characteristic of those techniques is that the epitaxial film growth requires multiple sources for the film elements, for example separate sources for zinc (Zn) and sulphur (S) are required for the epitaxial growth of ZnS films. Therefore, such techniques can have the disadvantage of being rather complex processes, during which a large number of variables must be controlled. This often results in high costs associated with the operation of machines for epitaxial film growth.

Epitaxial thin films are desirable for a large number of applications including light emitting layers for diodes, as active layers in optical/electro-optical thin film devices and as coatings. In this application, the single-crystal like characteristics of epitaxial films are

utilised, which are typically superior to the characteristics of polycrystalline films.

Summary of the Invention

In accordance with a first aspect of the present invention there is provided an epitaxial film grown using single source chemical vapour deposition.

In one embodiment, the epitaxial film comprises ZnS.

Preferably, the ZnS is grown using zinc diethyldithiocarbamate as precursor for the single source chemical vapour deposition.

In accordance with a second aspect of the present invention there is provided a process comprising the steps of utilising single source chemical vapour deposition for growing an epitaxial film on a substrate.

In one embodiment, the epitaxial film is ZnS.

The process may comprise the use of zinc diethyldithiocarbamate as a precursor for the single source chemical vapour deposition.

Preferably, the substrate comprises a silicon (111) substrate.

In accordance with a third aspect of the present invention, there is provided a substrate coated with a coating comprising an epitaxial film grown using single source chemical vapour deposition.

Preferably, the substrate comprises silicon (111).

In one embodiment, the epitaxial film comprises ZnS.

In accordance with a fourth aspect of the present invention, there is provided a process for growing an epitaxial film, the process comprising the steps of cleaning a substrate, heating the substrate to a deposition temperature, the sublimation of a single source chemical vapour deposition precursor;

the pyrolysis of the precursor molecules on the heated substrate; and

the formation of the epitaxial film on the heated substrate.

Preferably, the substrate comprises silicon (111).

In one embodiment, the epitaxial film comprises ZnS.

Preferred forms of the invention will now be described, by way of example only, with reference to the accompanying drawings.

Brief Description of the Drawings

Figure 1 is a schematic drawing of a deposition chamber embodying the present invention.

Figure 2 shows angle dependent X-ray photoelectron defraction measurements of epitaxial films embodying the present invention.

Figure 3 is schematic drawing illustrating a side view of a ZnS crystalline structure.

Figure 4 shows an X-ray photoelectron spectroscopy wide scan of a ZnS film embodying the present invention.

Figure 5 shows an angle dependent X-ray photoelectron defraction measurements of a ZnS film after sputtering.

Figure 6 shows energy dependent X-ray photoelectron defraction measurements of an epitaxial film embodying the present invention.

Figure 7 is schematic drawing illustrating a side view of a ZnS crystalline structure.

Figure 8 is a schematic drawing illustrating the formation of an epitaxial film embodying the present invention.

Figure 9 is a block diagram illustrating the growth of epitaxial films embodying the present invention.

Detailed Description of the Preferred Embodiments

In Figure 1, a high vacuum deposition chamber 10 (base pressure 10^{-7} Torr) comprises a resistively heated Knudsen cell 12 loaded with a zinc diethyldithiocarbamate precursor powder (not shown) for the single source chemical vapour deposition (SSCVD). A silicon Si(111) substrate 19 is mounted on a sample holder 16 on a heater 100 and the epitaxial film (not shown) is formed on the substrate 19. The chamber 10 further comprises a view port 11, a port 13

to which a vacuum pump (not shown) is connected and a flexible flange 15 as part of a x,y,z manipulator 17 for the heater 100.

As illustrated in Figure 8, sublimed zinc diethyldithiocarbamate molecules 80 impinge on the heated substrate 19. In the diethyldithiocarbamate molecules 80, the zinc atom is in a similar environment to that of zinc in crystalline ZnS. The SSCVD growth of the ZnS epitaxial film 84 proceeds via the pyrolysis of $Zn[S_2CN(C_2H_5)_2]_2$ on the heated substrate 19 (400°C):

$$Zn[S_2CN(C_2H_5)_2]_2 \rightarrow ZnS + C_2H_5NCS + (C_2H_5)_3NCS_2 \qquad (1)$$

C_2H_5NCS and $(C_2H_5)_3NCS_2$ decompose into by-products such as C_2H_4, CS_2 and $(C_2H_5)NH$ which are volatile in vacuum and therefore do not remain on the heated substrate 19 during the ZnS epitaxial film growth.

In this embodiment epitaxial film growth of ZnS was found on the Si (111) surface (lattice mismatch ~0.2%).

As shown in Figure 9, in one embodiment the growth of epitaxial films comprises the cleaning of the Si substrate (step 90), the heating of the Si substrate (step 92), the sublimation of the diethyldithiocarbamate precursor (step 94), the pyrolysis of the diethyldithiocarbamate molecules on the heated substrate (step 96) and the formation of the epitaxial ZnS film on the heated substrate (step 98).

The cleaning of the Si(111) substrates (step 90) in one embodiment comprises the sequence of steps outlined in Table 1.

1	annealing in oxygen	1050°C	30 min
2	rinse in deionised H_2O	room temp (ultrasonic bath)	5 min
3	rinse in EtOH	room temp (ultrasonic bath)	5 min
4	rinse in Iso-propyl alcohol	room temp (ultrasonic bath)	5 min
5	N_2 blown dry		30 sec
6	$12H_2O$: $7NHF_4$: 1HF	room temp	10 min

7	rinse in deionised H_2O	room temp	1 min
8	N_2 blown dry		30 sec
9	$5H_2O$: 1HCl : $1H_2O_2$	80°C, oil bath	10 min
10	rinse in deionised H_2O	room temp	1 min
11	N_2 blown dry		30 sec
12	$12H_2O$: $7NHF_4$: 1HF	room temp	10 min
13	rinse in deionised H_2O	room temp	1 min
14	N_2 blown dry		30 sec
15	$5H_2O$: 1HCl : $1H_2O_2$	80°C, oil bath	10 min
16	rinse in deionised H_2O	room temp	1 min
17	N_2 blown dry		30 sec
18	$12H_2O$: $7NHF_4$: 1HF	room temp	10 min
19	rinse in deionised H_2O	room temp	1 min
20	N_2 blown dry		30 sec
21	$5H_2O$: 1HCl : $1H_2O_2$	80°C, oil bath	10 min
22	rinse in deionised H_2O	room temp	1 min
23	N_2 blown dry		30 sec
24	NH_4F (40%) or HF (5%)	room temp	10 min
25	rinse in absolute EtOH	room temp	2 min
26	Mounting onto sample holder/heater 16		
27	loading into deposition chamber 10		
28	heating for removing surface contaminants	350°C, vacuum (10^{-8} torr)	15 min

In will be appreciated, however, that other cleaning step sequences and different treatment times may be applied, which may e.g. comprise sputtering and annealing steps in the high vacuum deposition chamber 10 (Figure 1).

<u>Film Characterisation</u>

The resulting epitaxial films were characterised using X-ray photoelectron spectroscopy (XPS) and X-ray photoelectron diffraction (XPD). For details on those experimental characterisation techniques reference is made to W. Eberhardt in Synchrotron Radiation Research, Vol. 1, edited by R.Z. Bachrach, Plenum press, New York, 1992 and C.S. Fadley in Synchrotron Radiation Research, Vol. 1, edited by R.Z. Bachrach, Plenum press, New York, 1992.

Figure 2 shows an angle dependent XPD scan of the Zn $2p_{3/2}$ intensity distribution for ZnS epitaxial films at thicknesses ranging from ~5 to 2000Å. The film thicknesses were estimated using the intensity attenuating of the XPS Si substrate peaks, as e.g. discussed in C.S. Fadley in Synchrotron Radiation Research, Vol. 1, edited by R.Z. Bachrach, Plenum press, New York, 1992. The XPD measurements were performed after subsequent SSCVD deposition cycles.

The XPD patterns exhibit an intense and broad peaks 20, 22, and 24 at $\theta=0°$ which are the result of forward-scattering of Zn $2p_{3/2}$ photoelectrons by neighbouring atoms. In ZnS, every zinc atom is surrounded by four sulfur atoms in a tetrahedral arrangement which results in either a cubic (sphalerite) or a, slightly distorted, hexagonal (wurtzite) structure.

The enhanced XPD intensities 20, 22, 24 at $\theta=0°$ in curves a, b, and c of Figure 2 respectively therefore indicate that the film molecules have preferred orientation at the film-to-substrate interface and the Zn $2p_{3/2}$ photoelectrons are scattered by the sulfur neighbours perpendicular to the substrate.

As illustrated in Figure 3, the forward scattering enhancement 20, 22, 24 at $\theta=0°$ in curves a, b and c of Figure 2 is likely the result of forward-scattering of $Zn2p_{3/2}$ photoelectrons emitted from the zinc atoms 30 at the sulphur atoms 32, which are positioned directly above the zinc atoms 30 at a distance of 2.3 Å in an ideal ZnS cubic crystal structure.

In Figure 4, a XPS wide scan 40 for a typical ZnS epitaxial film embodying the present invention is shown. In the curve 40 shown in Figure 4, the silicon substrate peaks can also be observed, which are not fully attenuated due to the thinness of the ZnS epitaxial film on which the XPS measurement shown in Figure 4 was performed. The

chemical composition obtained from XPS scans such as the one shown in Figure 4 were in agreement with those obtained for a ZnS reference sample.

In Figure 5, the curve 50 shows the XPD measurement for the 2000Å thick film of curve c of Figure 2 after Ar^+ ion etching.

During the Ar^+ ion etching, highly energetic (2000 electron Volt (2keV)) impact on the film surface, resulting in a disordering of the crystallographic structure of the surface. In curve 50 of Figure 5, the XPD scan therefore does not indicate a significant forward scattering enhancement at $\theta=0°$.

Energy dependent XPD was employed to probe the in-plane orientation of the film molecules. The sample position and angle remained unchanged while the energy of the incoming X-rays was varied.

The energy dependent XPD features shown in Figure 6 are a result of diffraction of S 2p photoelectrons in the ZnS atomic network. The photoelectron take-off angle was 19° with respect to the surface plane, i.e. the measurement was sensitive for crystallographic order within the plane of the substrate. As diffraction is a long range order process (diffraction of photoelectrons requires single crystalline surfaces) the observation of peaks 60, 62, 64 demonstrates that the film is of epitaxial quality.

As illustrated in Figure 7, the peaks 60, 62, 64 in the measurement shown in Figure 6 are due to the forward scattering of S 2p photoelectrons emitted from the sulphur atoms 70 at zinc atoms 72, which are the next neighbours of the sulphur atoms 70 in the $[11\bar{1}]$ crystallographic direction 74, along which the measurement shown in Figure 6 was measured. The distance between the sulfur atoms 60 and the Zn atoms 72 in an ideal ZnS cubic crystal structure is 2.3 Å.

In the claims that follow and in the summary of the invention, except where the context requires otherwise due to express language or necessary implication, the word "comprising" is used in the sense of "including", i.e. the features specified may be associated with further features in various embodiments of the invention.

In the claims that follow and in the summary of the invention, except where the context requires otherwise due to express language or necessary implication, the word "comprising" is used in the sense of "including", i.e. the features specified may be associated with further features in various embodiments of the invention.

THE CLAIMS DEFINING THE INVENTION ARE AS FOLLOWS:

1. An epitaxial film grown using single source chemical vapour deposition.

2. A process comprising the steps of utilising single source chemical vapour deposition for growing an epitaxial film on a substrate.

3. A substrate coated with a coating comprising an epitaxial film grown using single source chemical vapour deposition.

4. A process for growing an epitaxial film, the process comprising the steps of:

- cleaning a substrate;
- heating the substrate to a deposition temperature;
- the sublimation of a single source chemical vapour deposition precursor;

the pyrolysis of the precursor molecules on the heated substrate; and

the formation of the epitaxial film on the heated substrate.

Dated this 22nd day of June 1999

UNISEARCH LTD

By their Patent Attorneys

GRIFFITH HACK

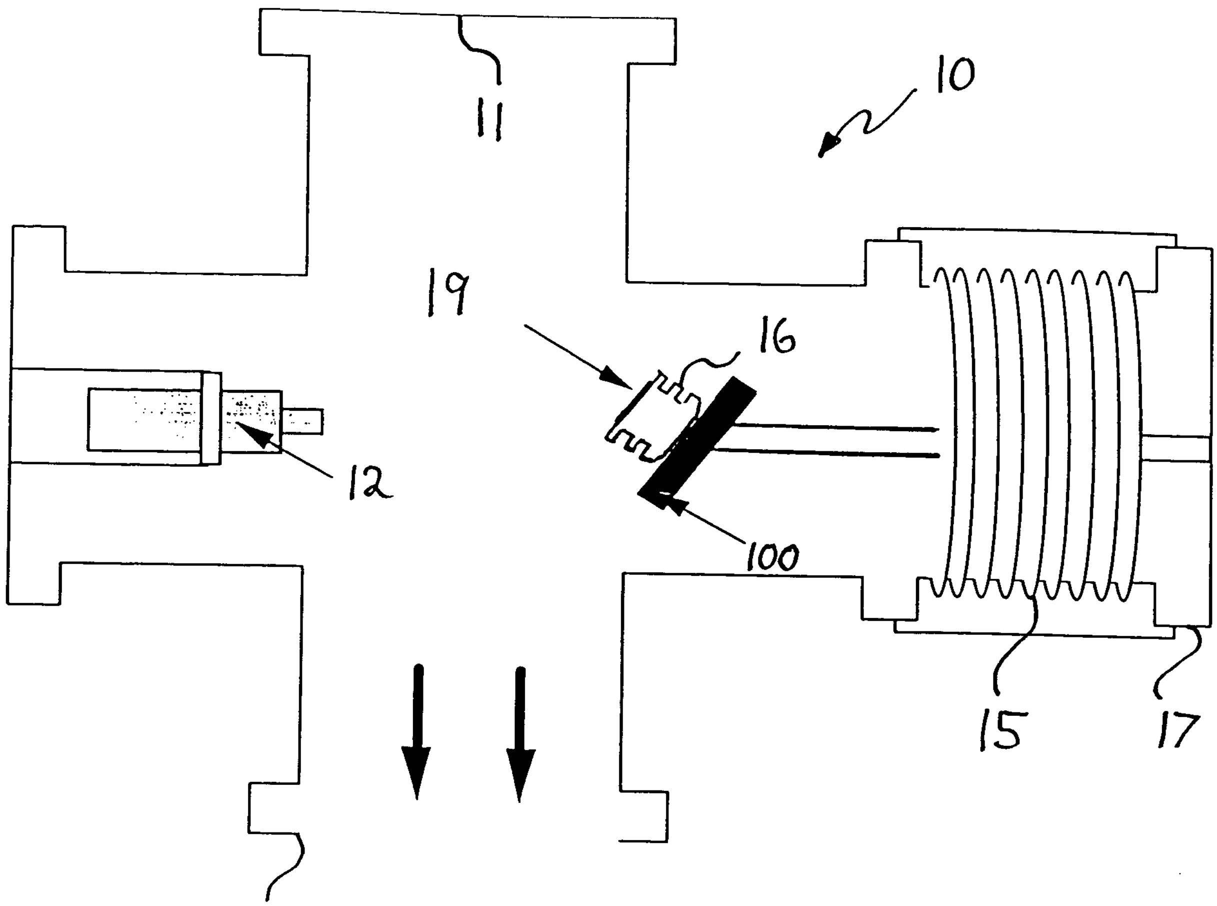

Figure 1

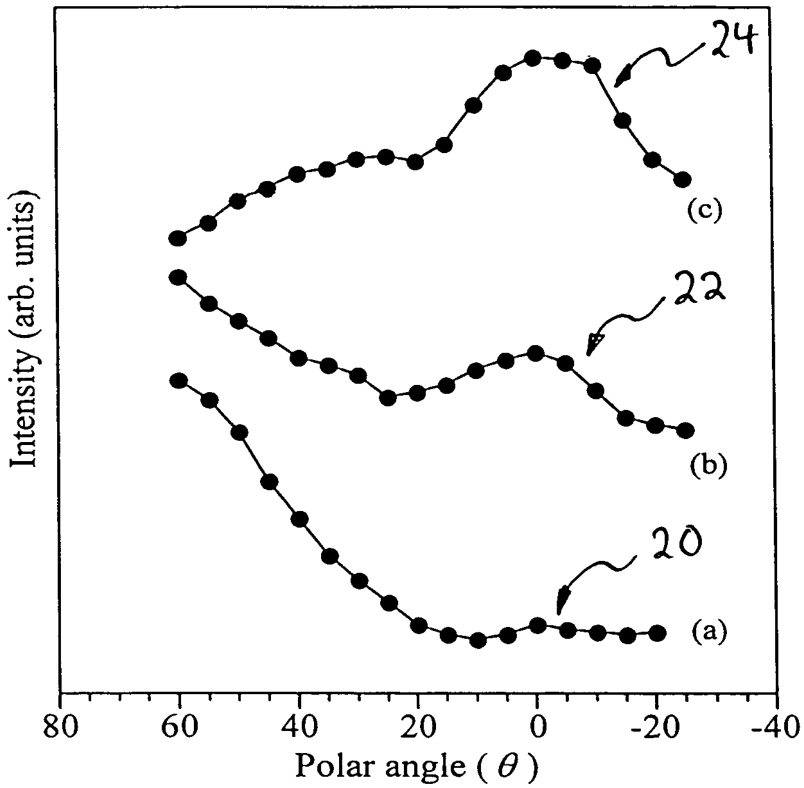
24
(c)
22
(b)
20
(a)
Intensity (arb. units)
80
60
40
20
0
-20
-40
Polar angle (θ)

Figure 2

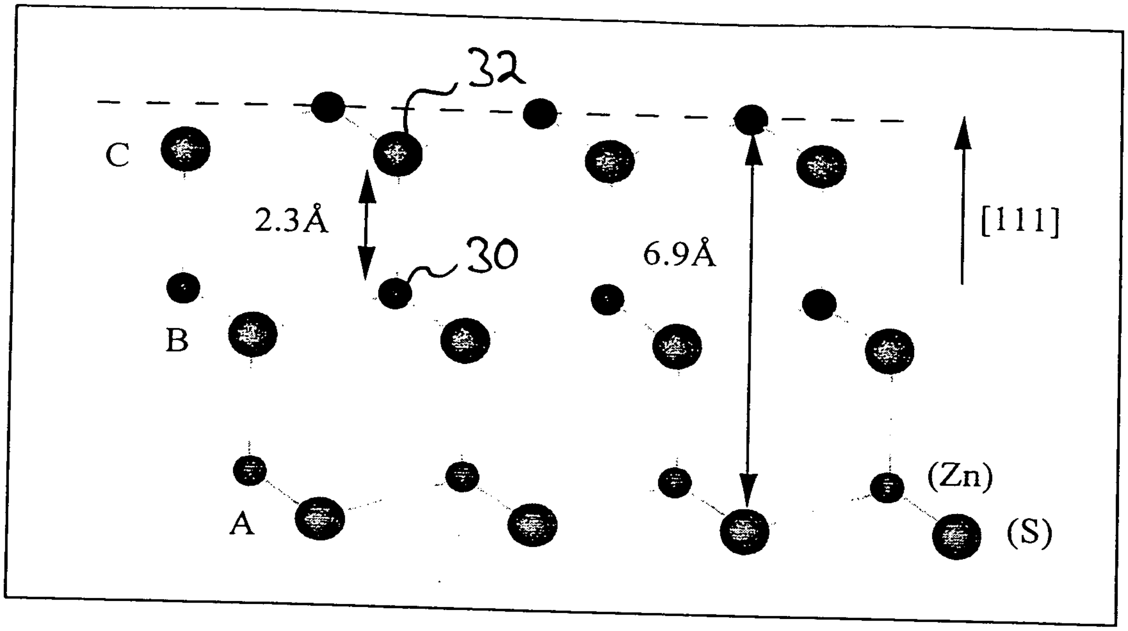

Figure 3

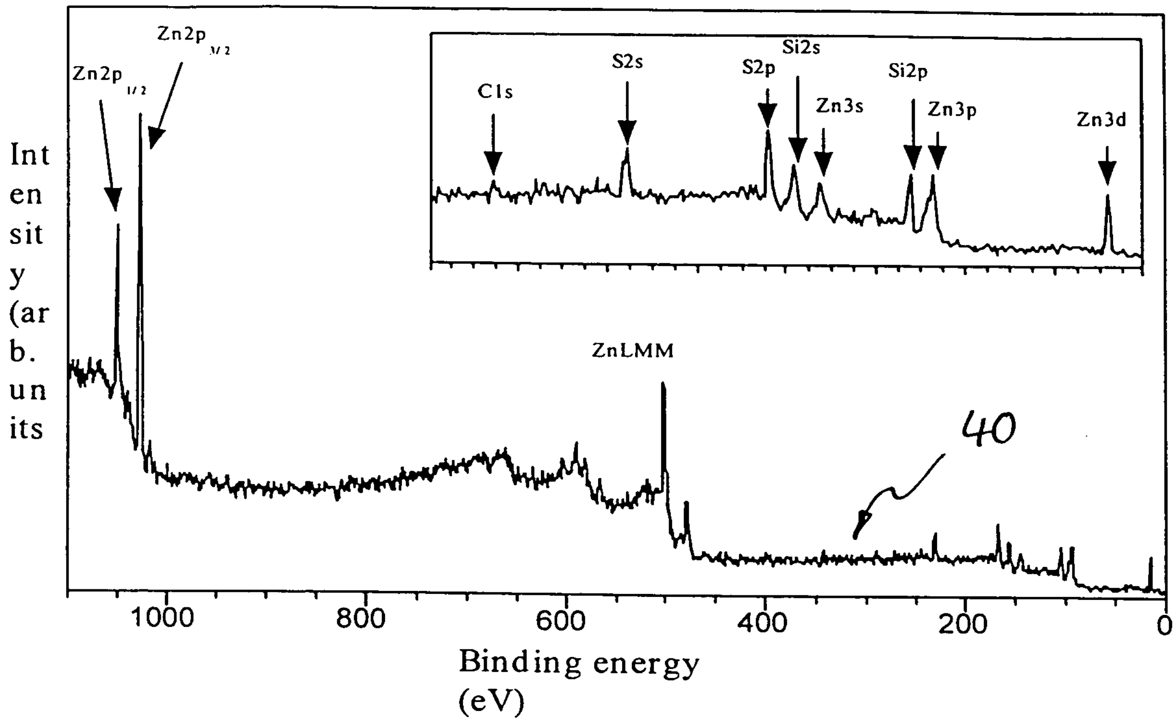
Zn2p 3/2
Zn2p 1/2
C1s
S2s
S2p
Si2s
Zn3s
Si2p
Zn3p
Zn3d
Int
en
sit
y
(ar
b.
un
its
ZnLMM
40
1000
800
600
400
200
0
Binding energy
(eV)

Figure 4

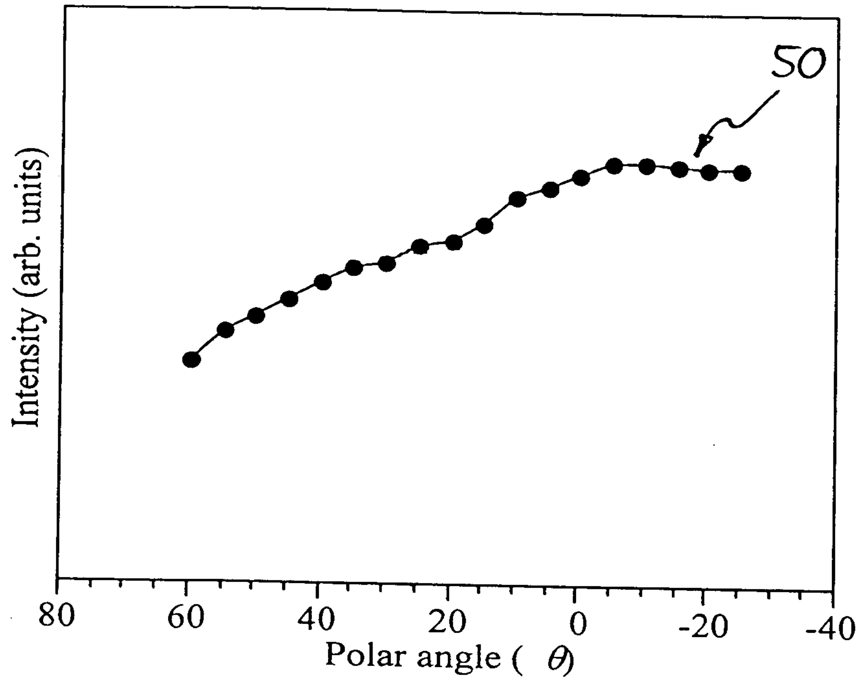

Figure 5

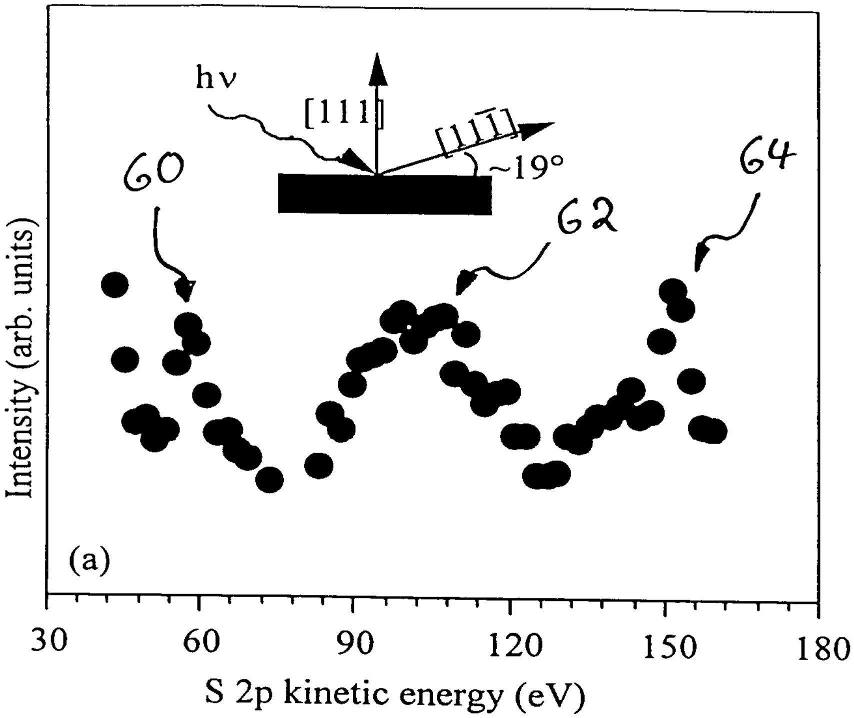

Figure 6

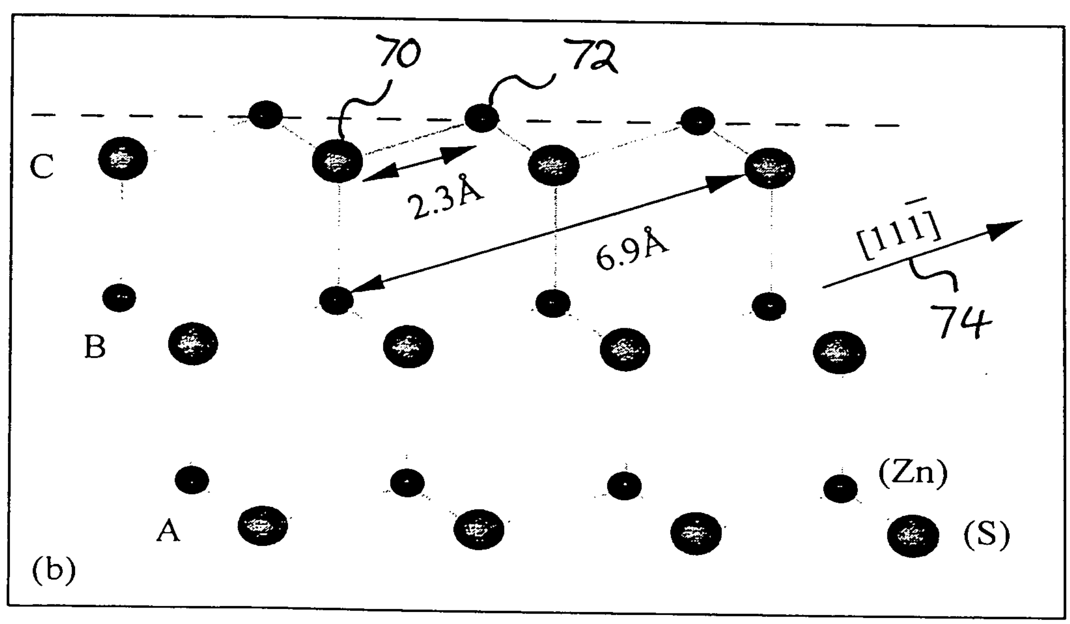

Figure 7

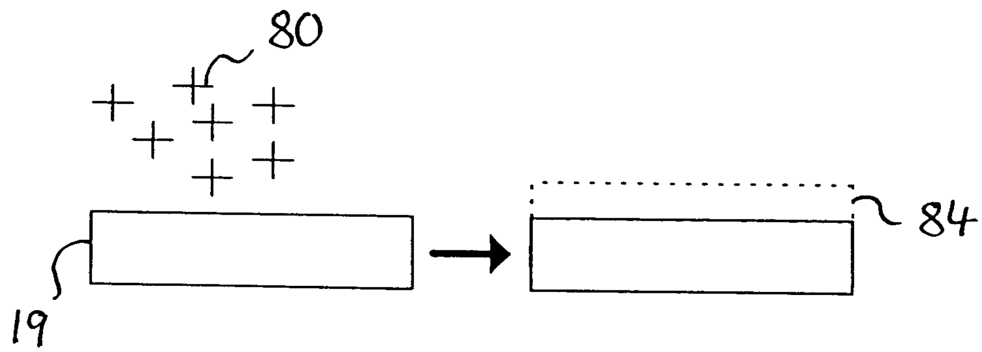

Figure 8

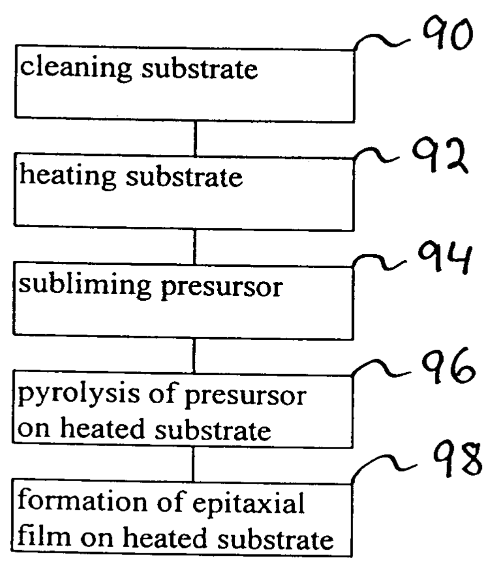

Figure 9